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DETERMINATION OF COMPLEX ENERGY CONSUMPTION OF METALLURGICAL PRODUCTION ON THE BASE OF MATHEMATICAL MODELLING OF INTERDISCIPLINARY LINKAGES

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The article suggests the possibility of using methods of structural analysis to the determination of the complex energy demands in metallurgical production, which would include both the energy demands of direct inputs of energy media and the energy demands of previous metallurgical stages and the energy demands of purchased materials and services.

Key words: metallurgical production, structural analysis, energy demandingness

Utvrđivanje kompleksne potrošnje energije metalurške proizvodnje na temelju matematičkog modeliranja interdisciplinarne povezanosti. Članak sugerira mogućnost rabljenja metoda strukturalnih analiza za utvrđivanje kompleksnih energetskih zahtjeva metalurške proizvodnje, gdje su uključeni oba energetska zahtjeva: izravna ulazna energija i energetski zahtjevi prethodnog metalurškog stadija te energetski zahtjevi utroška materijala i usluga.

Ključne riječi: metalurška proizvodnja, strukturalna analiza, energetski zahtjevi

INTRODUCTION

Economic development is generally associated with increasing consumption of materials and energies. Despite continuous improvement of energy consumption parameters of the economy, in particular in industry, the CR is still far above the level of energy demands of the highly developed EU countries [1].

Energy demands of GDP creation reflect the demands posed on energy consumption by certain sectors. Energy demands of GDP creation in the CR is high in comparison with the EU countries average, even though it has been steadily declining since 2004 (in 2008 27 167,11 *kgoe*/1000 *EUR*, CR 525,30 *kgoe*/1000 *EUR*). High energy demands are especially evident in transportation (in 2008, 920,6 *MJ/k. CZK*) and industry sectors (in 2008 418,5 *MJ/k. CZK* [2].

However, the impacts of high energy demands are immense: the necessity of higher energy production, with associated high emissions of pollutants and greenhouse gases, which is linked to increased negative impacts on the environment and human health. According to the Comprehensive Energy Scenario, which is part of the National Energy Policy CR, the aim is to maximize the energy efficiency, i.e. to achieve the highest possible production and to ensure the range and quality of services at the lowest possible demands for energy resources. According to Mikušová [3], it is one of the fundamental tasks delegated to top management in all sectors of the national economy. The most significant contemporary methods used to identify savings of resources of various kinds include, for example, the process analysis [4].

Given that the long-term strategic objectives of the energy policy both in the CR and in the EU include reducing energy demands, the requirement for decreasing the consumption of all types of energies raises the need to identify and know the value of all the energy necessary to produce the unit of production.

DETERMINING THE ENERGY DEMANDS OF METALLURGICAL PRODUCTION IN THE CZECH REPUBLIC

At present, the market price of steel and the final metallurgical products does not fully reflect the real costs of their production because of differences in tax and customs policies of the individual states, due to the effects of inflation, the exchange rate effects, etc. The value of their energy demands expressed in technical units may thus appear as a significant objective factor for comparison of different methods of production of steel and the final metallurgical products [5].

In the past, many authors and professional companies (for example: Ferrous metallurgy company, Eko-WAT civic association [6], Czech Energy Agency) have attempted to calculate the energy demands of the individual stages of metallurgical production in the Czech Republic. According to the degree of approximation, their approach can be roughly characterized as follows:

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- models identifying the energy demands of the individual production stages solely on the basis of calculation of direct inputs of the energy bearers (electricity, gas, coal, coke) into the respective production stage (for example production of converter steel). Only in exceptional cases, the model reflected energy demands of previous production stage (for example energy demands of iron production to energy demands of steel production) through calculation of the specific consumption (initial weight).
- models using certain modification of the calculation procedure in which the individual items of the calculation formula of the given production stage are "assessed" by the so called contribution of energy demands (CED). The CED values used to assess the detailed calculation items are quite difficult to obtain. A problem occurs mainly in case of imported raw materials (ores, ferro-alloys), but also, for instance, in case of items such as depreciation, wages, financing costs, etc.

Experimental part

In the opinion of the authors of this article, the determination of the complex energy demands in metallurgical production, which would include both the energy demands of direct inputs of energy media and the energy demands of previous metallurgical stages and the energy demands of purchased materials and services, can be successfully addressed using the method of structural analysis. A structural model of the energy demands of metallurgical fields (products) has been constructed as a combination of the classical structural model of metallurgical fields and the details of the individual fields, calculated on the basis of contributions of "energy demands" of selected calculation items.

The structural model assembled by the team of authors has the following form:

- Quadrant I - table of coefficients of direct consumption of variables - metallurgical fields (selected fields are broken down by technologies)
- Quadrant IIIa - external purchases of the fields included in quadrant I
- Quadrant IIIb - calculation of energy demands according to the specified items of the calculation formula expressed in units of energy demands (*GJ/t*)

The energy demands of selected cost items in the individual stages of metallurgical production have been calculated using data from the Czech Statistical Office, metallurgical annual reports, company VUPEK and other available materials. The industry calculation formulas have been used as a guide, but given the specific nature of the calculation of the energy demands, the calculation process has ignored those cost items that are associated with the energy demands only imprecisely and indirectly (interests, insurance, depreciations, wages, security, etc.) On the other hand, the calculation may also take in activities that are not included in the calculation formula of the total costs, but they can be energetically significant, such as energy demanding disposal of some environmental burdens resulting from metallurgical production. The energy demands of the calculation formula specified items are not expressed in *CZK*, but in the units of energy demand (*GJ/t*).

RESULTS

The comparison of the value of energy demands of selected metallurgical fields from direct energy media inputs and from complex energy demands, including the energy demands of the contributions from material inputs and services using the methodology of structural analysis, took advantage of published and widely available technical retrospective data. These files of aggregated data have became the basis for establishing the fundamental matrix of production and consumption relations and subsequently, by means of a simple software transformation, they were used to calculate the matrix of the so called complex consumption coefficient (both direct and indirect), which expresses the continuous, complex calculation of energy consumption reflecting the energy demands of consumed products in all previous stages. The results of calculations of the energy demands of the selected metallurgical fields from direct energy media inputs (DE) and the complex energy demands of the selected metallurgical fields, including the contributions of energy demands from material inputs and services (CE), are presented in Table 1.

Table 1 **Comparison of energy demands of selected metallurgical fields from direct energy media inputs (DE) and complex energy demands of selected metallurgical fields (CE)**

Selected fields of metallurgy	DE (GJ/t)	CE (GJ/t)
Coke	35,68492	35,68492
Sinter	2,31169	3,75220
Pig iron	16,57752	21,54334
Steel oxygen converters, TM furnaces	2,72526	19,71723
Oxyvit steel	2,84579	20,53286
EAF 17153 steel	8,67303	124,51745
EAF St 52-3 steel	8,54280	17,18179
Shaped iron	3,45042	26,60943
Hot formed steel bands	3,45042	25,13938
Thin sheets	3,45042	26,12524
Thick sheets	3,45042	27,15355
Seamless pipes	13,53362	37,19430
Steel casting	17,86092	47,06997
Cast iron	17,52262	45,52896
Free gorged pieces	23,04320	50,07060

DISCUSSION

The comparison shows that the energy demands (ED) of the individual production stages, calculated only from the primary energy inputs to the given stage, are vastly different from the complex perspective that includes both the ED from the direct energy media inputs as well as ED from previous metallurgical stages and ED of the purchased materials and services.

For example, according to the method determining ED only from the direct energy media inputs (DE), the least energy-demanding activity is steel production in converters (about 2,8 *GJ/t*), on the contrary, the most demanding is production in EAF (about 8,5 *GJ/t*) and this is practically regardless of the produced brand of steel. However, if the calculations of the ED include not only the ED of direct inputs, but we also count the ED from previous metallurgical stages and the ED of purchased materials and services, then the final value of the ED (complex energy demands) is completely different – the ED of converter steel is about 20 *GJ/t*, the ED of standard electric steel (EAF steel St 52-3) is 17,2 *GJ/t* and the ED of highly alloyed special steels (EAF steel 17 153) manufactured from ferro-alloys (without the use of sorted alloy scrap) is 124,5 *GJ/t*.

The outcome of the above performed analysis for example shows that ferro-alloys represent one of the energetically most demanding parts of metallurgical production. In production of electric alloy steel (EAF 17153 steel), the alloying elements can be supplied either as separated alloy waste or as ferro-alloys. The values in Table 1 clearly illustrate how the complex ED of steel production increases when the ED of ferro-alloys production is taken into account. The sorting and use of alloy scrap instead of ferro-alloys charge can bring significant energy savings. The values in Table 1 also show that the production of standard electric steel from scrap in EAF (EAF steel St 52-3) is energetically more profitable than the production of steel in oxygen converters working with liquid iron produced from ores imported from enormous distances (e.g. from South America, Australia) by ships and railway service (it is also necessary to reload ore from broad-gauge) and with nearly half the content of tailings.

Thanks to the knowledge of the complex coefficients, we can therefore more objectively assess the order of energy demands of the individual steel production technologies and evaluate the importance of steel waste (and especially sorted alloyed waste) in steel production charge.

That is why the structural models calculating the complex coefficients of energy demands become a powerful tool for objective decision-making and management in metallurgical plants.

CONCLUSION

According to an independent estimate made by ENVIROS s.r.o. company, the sector of “Iron and steel production” is a sector with the highest professional estimate of technical potential for energy savings in the manufacturing industry [6]. According to a study [6] the investment costs necessary to achieve the savings of 1 *GJ* can range between 800 and 2000 *CZK*, in exceptional cases even higher. The utilization of the complex coefficients of ED may have significant practical importance, since, for example, when considering the savings of fuels and energies, it can help to analyze and subsequently also optimize the composition of material and performance inputs, without any significant additional investment costs. The assembled model and the currently achieved calculation results serves as an argument proving that the structural analysis can be conveniently used to calculate complex energy demands of metallurgical production.

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